CESR-c R&D Program

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HEPAP - August 5, 2002

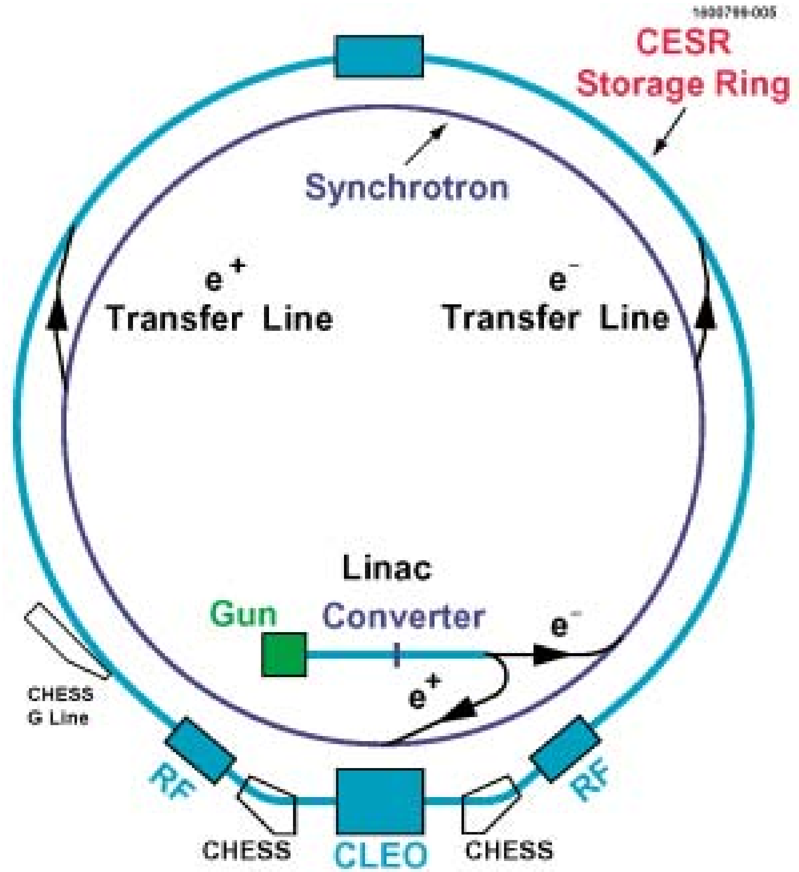
1. Objectives of the R&D program
2. Accelerator Physics Studies
3. Hardware Development

R&D Objectives

Why do we need R&D?

- Performance of e+e- colliders decreases below optimum energy due to a combination of decreasing beam “stiffness” and changes in radiation parameters.

- CESR-c will employ multiple low-current bunches and radiation-enhancing wiggler magnets to achieve the highest possible luminosity in the Charm energy regime.



R&D Objectives (2)

- Validate choice of CESR-c operating parameters
- Explore operation of high current storage rings with wiggler dominated radiation
- Develop hardware, including economical wiggler magnets, for CESR-c with potential application to other colliding beam or damping ring accelerators.

R&D Objectives

- CESR-c Parameters

Beam Energy [GeV]	1.55	1.88	2.5	5.3
Luminosity [$\div 10^{30}$]	150	300	500	1250
i_{bl} [mA/bunch]	2.8	4.0	5.1	8.0
I_{beam} [mA/beam]	130	180	230	370
ξ_y	0.035	0.04	0.04	0.06
ξ_x	0.028	0.036	0.034	0.03
σ_E/E_0 [$\times 10^3$]	0.75	0.81	0.79	0.64
$\tau_{x,y}$ [msec]	69	55	52	22
B_W [Tesla]	2.1	2.1	1.75	1.2
β_y^* [cm]	1.0	1.0	1.0	1.8
ε_x [nm-rad]	230	220	215	220

Accelerator Physics Studies

Accelerator Physics topics:

- Linear Optics
- Non-linear optics
- Beam lifetime
- Bunch length
- Single beam stability
- Injection
- Beam energy & width

Accel. Phys. - Linear Optics

Challenges:

Achieve desired single beam parameters in Charm energy region.

Accommodate vertical focusing effects of wigglers ($kl \sim 0.073 \rightarrow \Delta Q \sim 0.1$ each wiggler)

Solutions:

Individual control of quadrupoles (and sextupoles) allow maximum flexibility for optics

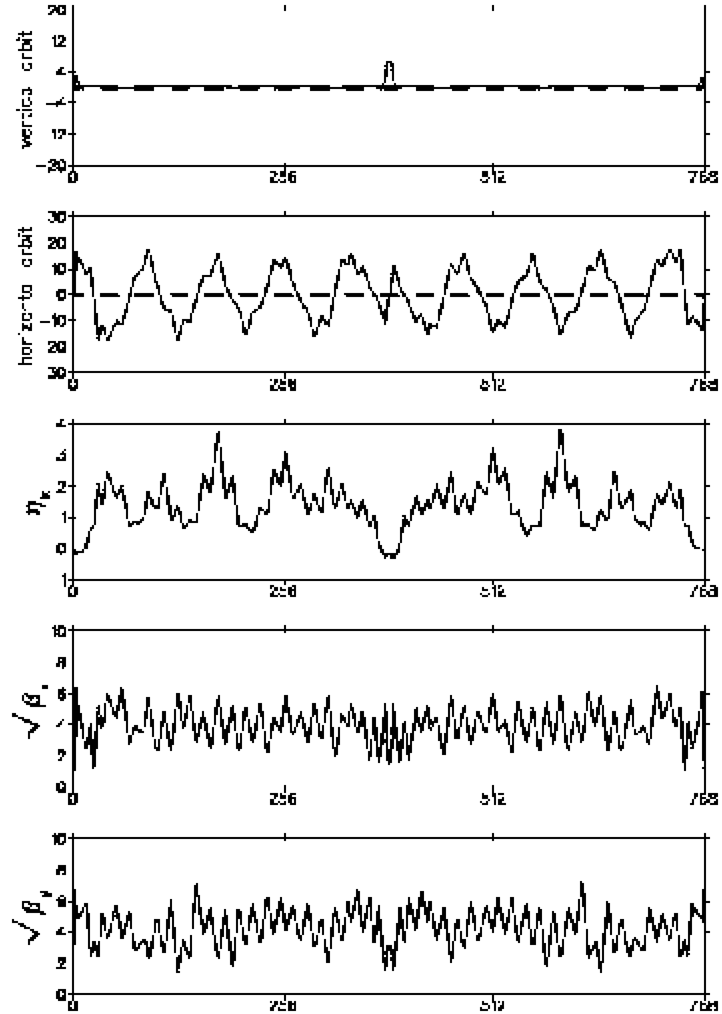
Careful modeling of wiggler properties

Accel. Phys. - Linear Optics (2)

Linear Optics

Lattice parameters

Beam energy [GeV]	1.89
β^*_v [mm]	10
β^*_h [m]	1
Crossing angle [mrad]	2.7
Q_v	9.59
Q_h	10.53
Number of trains	9
Bunches/train	5
Bunch spacing [ns]	14
Accelerating Voltage [MV]	10
Bunch length [mm]	2.1
Wiggler Peak Field [T]	18.2
Wiggler length [m]	1.3
Number of wigglers	14
ε_x [mm-mrad]	0.16
σ_E/E [%]	0.081



Accel. Phys. - Linear Optics (concl.)

Linear Optics summary:

- Linear optics design meets specification for 1.55 GeV < E_{beam} < 5.72 GeV
- 1.0 T solenoid field compensated 1.55-2.5 GeV
- Vertical focusing of 14 CESR-c wigglers readily accommodated
- Measured parameters of 1.84 GeV test optics are as designed.

Accel. Phys. - Non-Linear Optics

Challenges:

Maintain total aperture comparable to physical aperture

Wiggler non-linearities will be significant

1. Vertical only - intrinsic
2. H & V - from field non-uniformity enhanced by wiggling path of beam

Solutions:

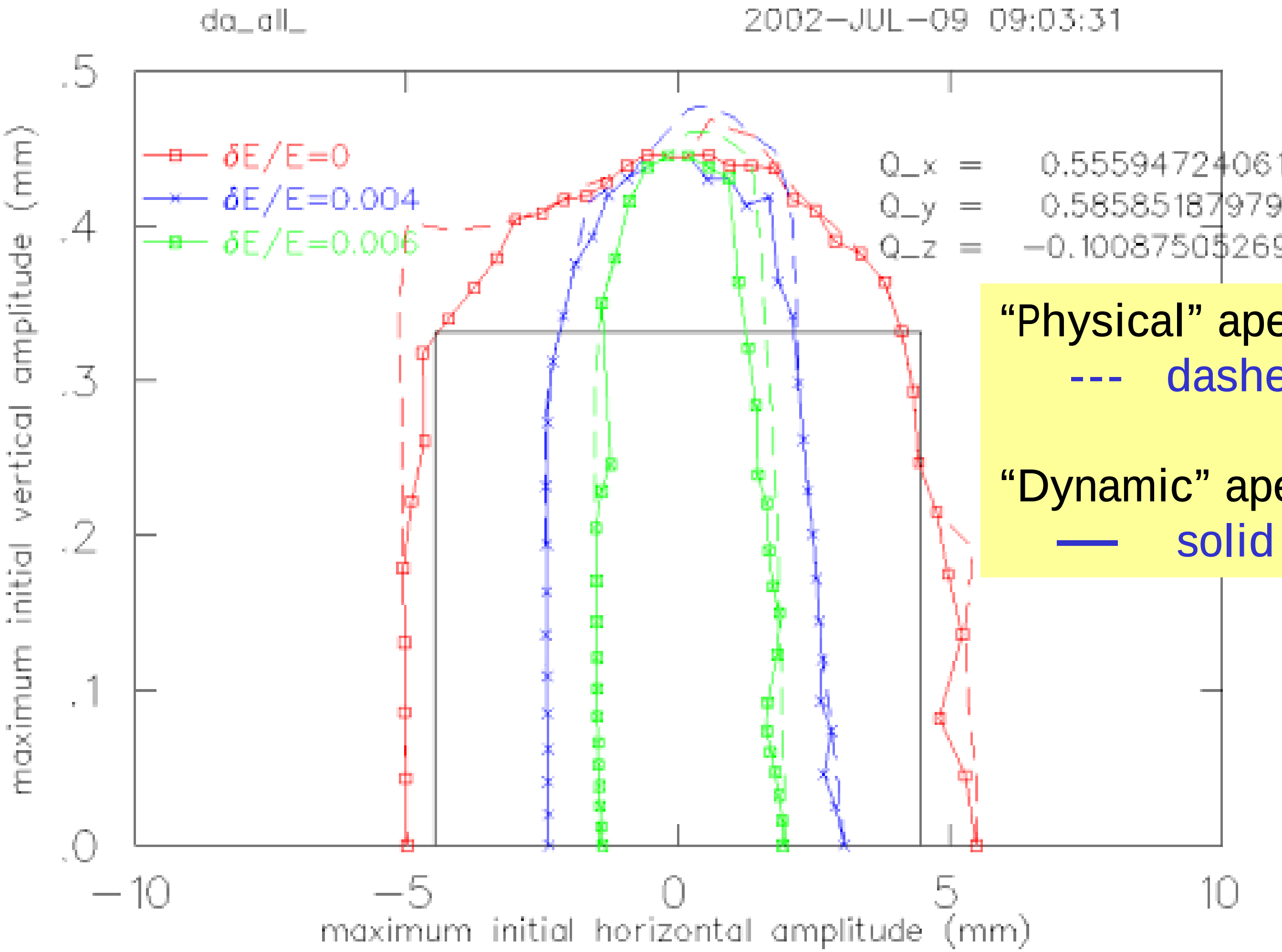
Extensive tracking studies with full treatment of wiggler fields provide insight and confirmation of performance.

Machine studies of effect of CHESS wigglers on beam properties

Machine studies (future) of effect of prototype wiggler on beam properties

Accel. Phys. - Non-Linear Optics (2)

Tracking with wigglers, sextupoles, pretzel orbit.



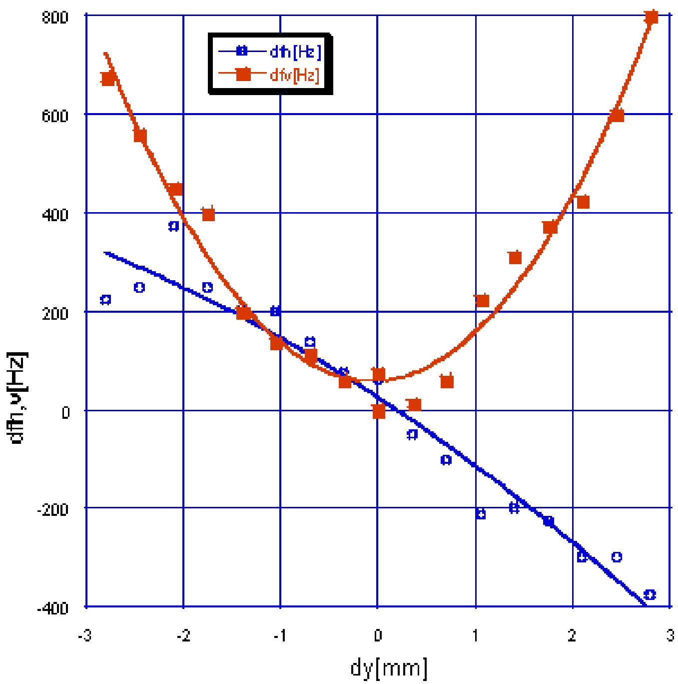
"Physical" apert.
--- dashed

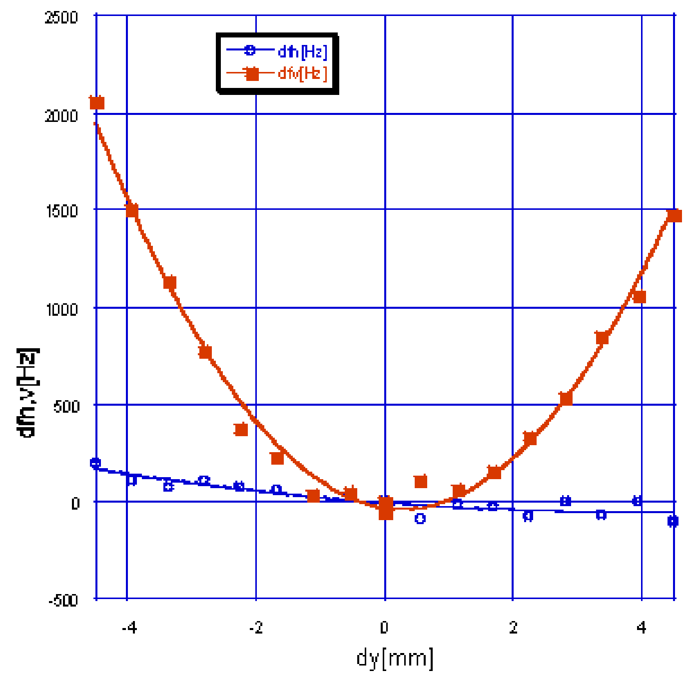
"Dynamic" apert.
— solid

Accel. Phys. - Non-Linear Optics (3)

Measurement of wiggler cubic non-linearity

$\frac{d^2 f_v}{dy^2}$ [Hz/mm^2]	CHESS/west wiggler measured	CHESS/west wiggler calculated	CHESS east wiggler measured	CHESS east wiggler calculated
	87.1(2.6)	79.0(4)	88.7(4)	91.6(5)





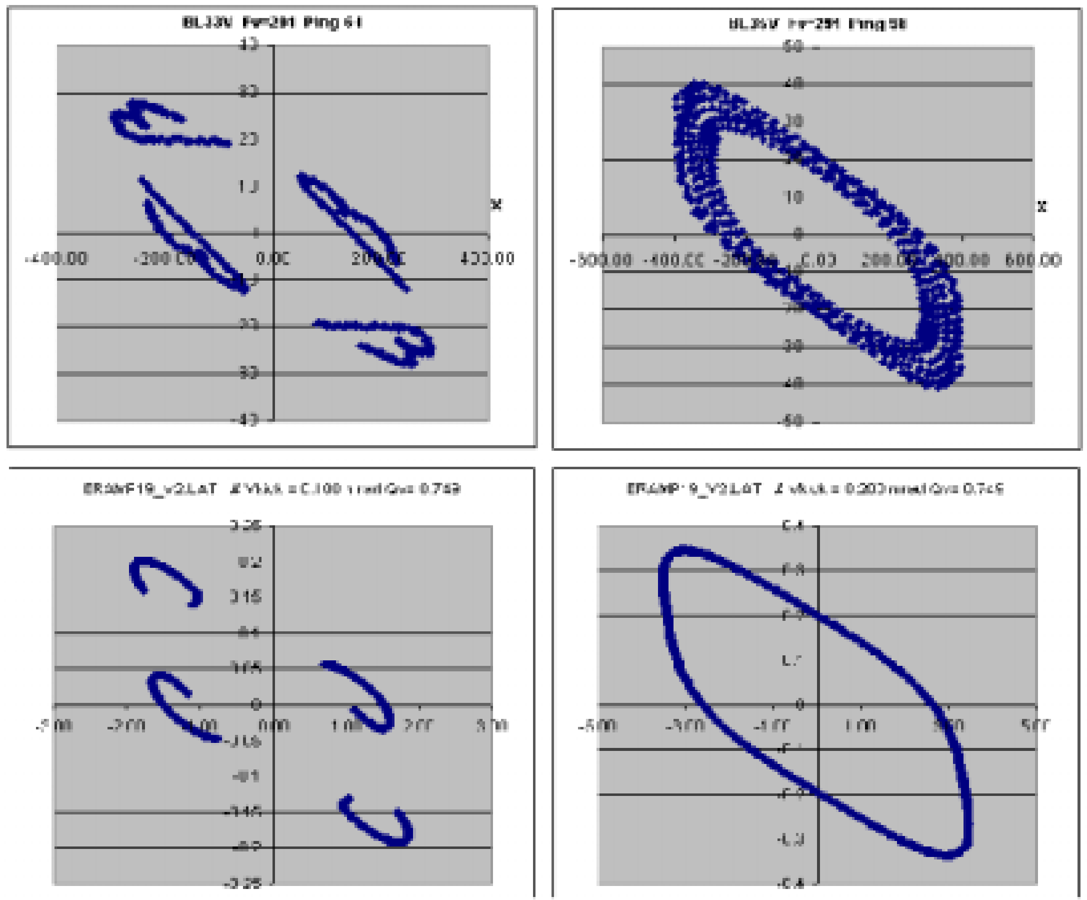
Accel. Phys. - Non-Linear Optics (4)

Large amplitude non-linear motion

Measured in CESR by kicking the beam to large amplitude and recording trajectory turn by turn

Tracking calculation

Q_v=0.749



0.1mrad kick

0.2mrad kick

Accel. Phys. - Non-linear Optics (concl.)

Non-linear Optics summary:

- Wiggler non-linearities must be controlled through careful design
- Present design for wigglers with dB/B <0.3% @4 cm results in satisfactory dynamic aperture if construction tolerances are controlled
- Many aspects of our model of CESR with wigglers at 1.84 GeV have been validated by measurements.

Accel. Phys. - Beam lifetime

Particle loss mechanisms (with design parameters - 1.55 GeV)

	Lifetime
• Beam-beam brems	13 hr
• Quantum excitation (RF bucket)	>30 hr
• Aperture (physical and dynamic)	~20 hr
• Beam-gas scattering (elastic)	~47 hr
• Beam-gas scattering (inelastic)	~43 hr
• Touschek scattering	~5* hr
• TOTAL LIFETIME	2.5 hr

* Lifetime measured ~6 hr @ 1.84 GeV, ~2x design bunch density

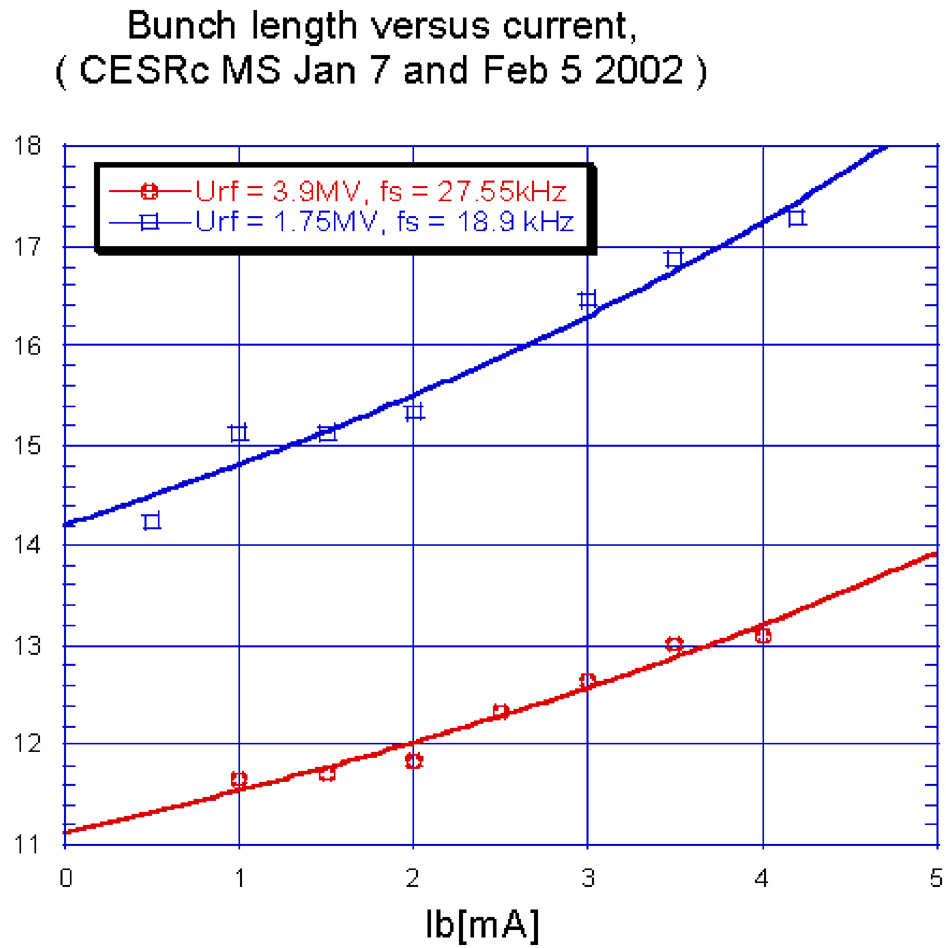
Accel. Phys. - Bunch length

Measurement of bunch lengthening:

Beam energy spread with 2 CHESS wigglers ~ 1/2 of CESR-c design → 1/2 RF voltage for same bunch length.

Higher voltage in CESR-c conditions will reduce bunch lengthening.

No sign (change in slope) of turbulent bunch lengthening.



Accel. Phys. - Single beam stability

Single beam current limits:

- 177 mA stored in single beam @ 1.84 GeV (180 mA design)
- >8 mA stored in single bunch (4 mA design)
- Bunch-by-bunch feedback in 3 dimensions
- Ion effects observed - omitting one or partial train is a fix.

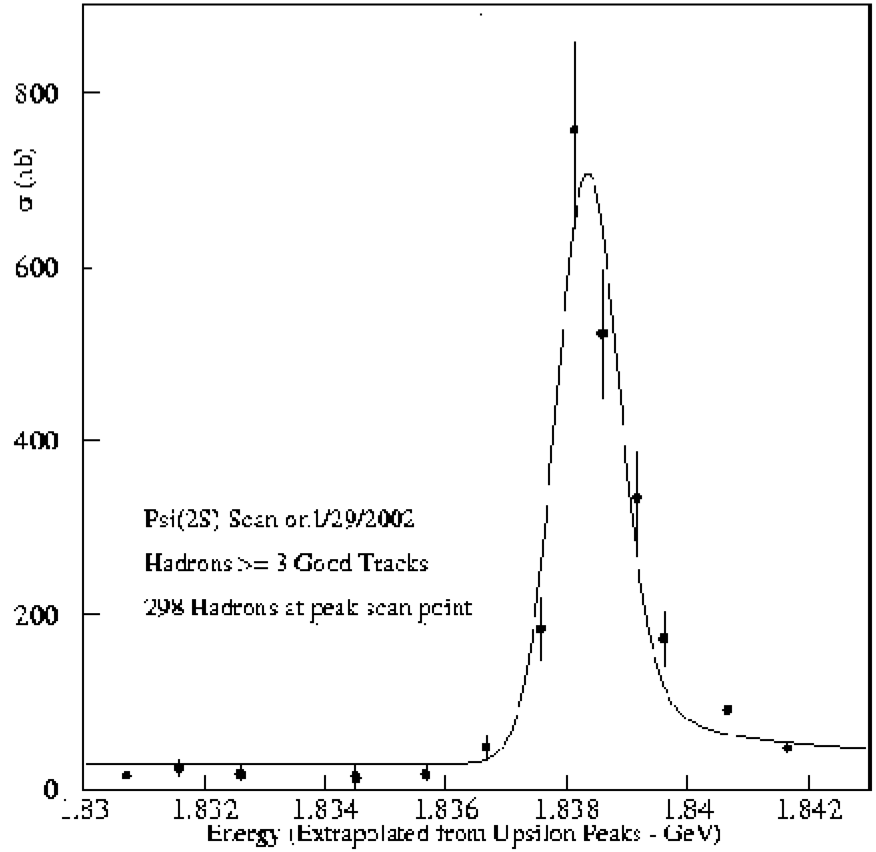
Accel. Phys. - Injection

Injection studies:

- Injection repetition rate at this time 15 Hz vs. 60 Hz at 5 GeV (250 vs 22 ms transverse damping time)
  30 to 60 Hz will be possible with full complement of wigglers.
- Ti windows in transfer line increase emittance of injected beams - transfer efficiency limited to ~50%, 20% with pretzel.
  Replacement with Be windows is expected to roughly double these figures.
- Long range beam-beam interaction will be stronger than at 5 GeV, but lower emittance will provide more aperture for separating beams. (bbi $\propto$ 1/(separation)^2)

Accel. Phys. - Data from CLEO

A scan of Ψ(2S) peak gave calibration of absolute energy and beam energy spread.



Hardware Development

Most of CESR systems are fully usable for low energy operation:

Magnet field quality ?	✓ All magnets OK to 1.55 GeV
Power supply stability ?	Marginal - being addressed
Vacuum system ?	✓ Wall pumping adequate to maintain < 1 ntorr pressure
Pulsed magnets ?	✓ All tested to 1.55 GeV levels
Injector/synchrotron ?	✓ Full beam currents easily achieved
Feedback systems ?	✓ Operating at 1.84 GeV
RF system ?	✓ Works adequately at 1.84 GeV → Power saving possible.

Hardware - RF Optimization

To achieve 1 cm bunch length with the large energy spread of CESR-c, 4 cavities are needed to provide 10 MV peak RF voltage.

Power lost by beam, even with wigglers, is small (<120 kW total including HOM).

One or more klystrons may be turned off, with the beam providing power to drive the cavities to operating field.

Tests have shown this mode of operation works well with 1 cavity driven by beam - 2 may be possible.

Control of phases between cavities simplified.

Hardware - Wiggler magnets

The largest hardware modification for CESR-c is construction of wiggler magnets.

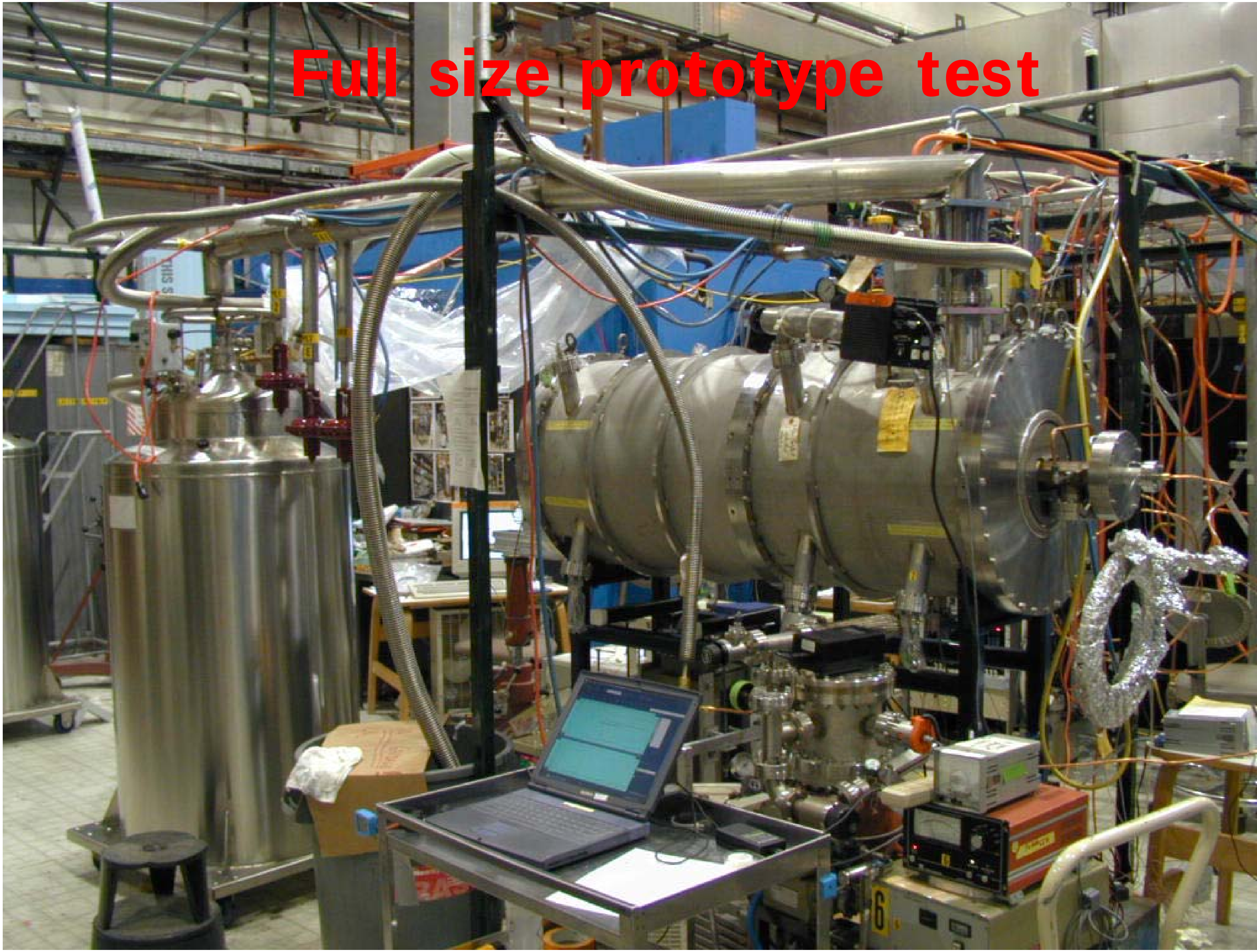
- 14 wigglers plus 2 spares
- 1.3 m active length each
- 2.1 T peak field
- 5.5 cm vertical aperture for beam pipe
- Excellent field quality - < 0.3% field variation

$\Rightarrow$ Superferric technology

Hardware - Wiggler magnets (2)

An extensive development program has produced a prototype wiggler meeting these requirements:

Full size prototype test



Single coil test facility

Hardware - Wiggler magnets (3)

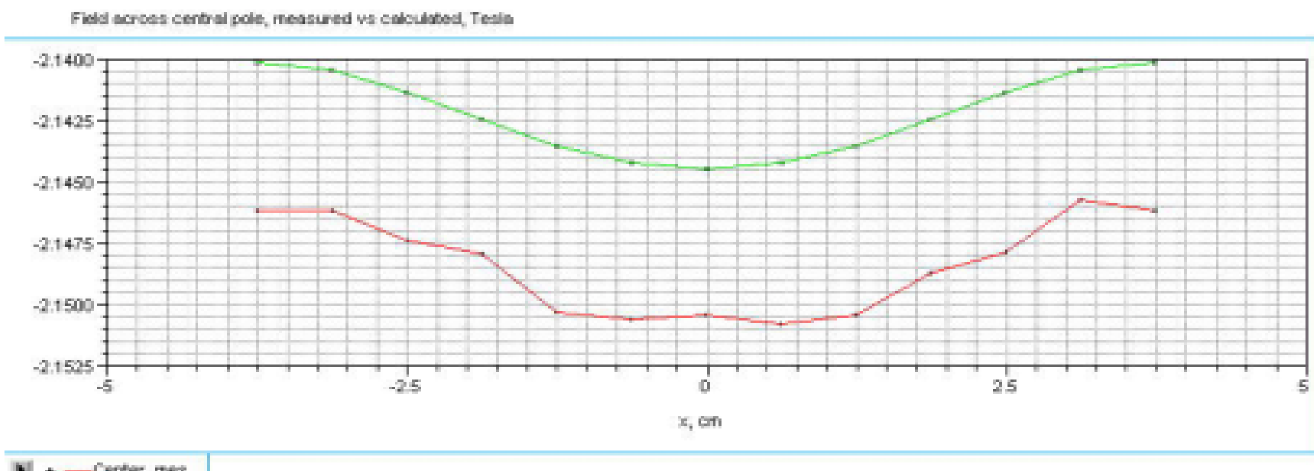
The prototype wiggler meets CESR-c requirements:

- Full size magnet tested to 125% of operating field.
- Cryogenic system functions properly during cooldown and operation.
- Detailed field maps generally consistent with 3-D calculations using Mermaid and TOSCA

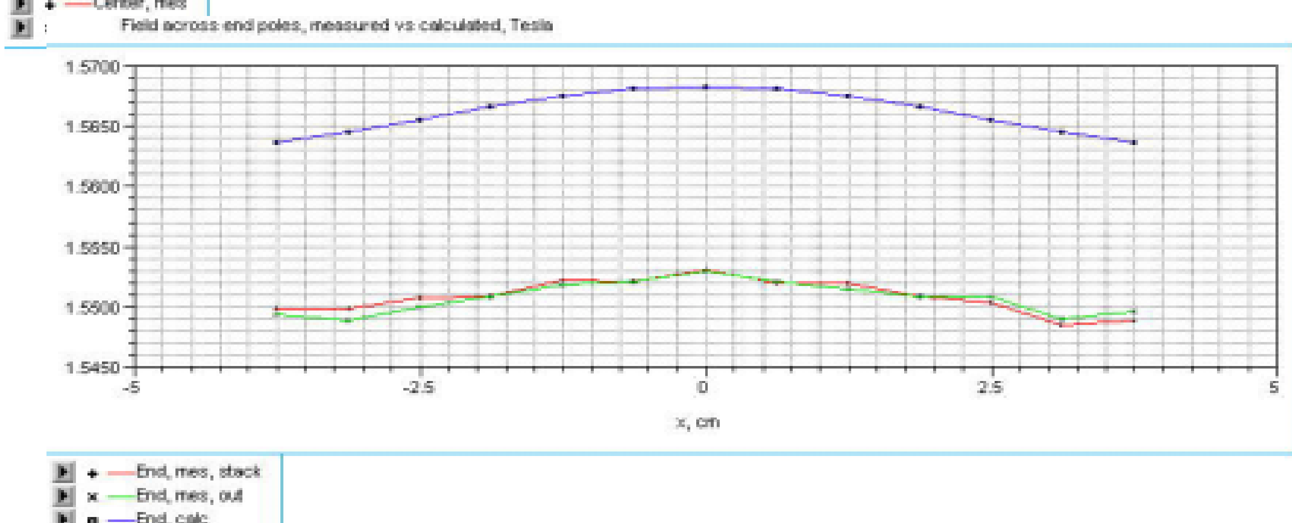
Hardware - Wiggler magnets (4)

Magnetic measurement across pole midplane:

Center Pole



End Pole



CESR-c R&D - Summary

The CESR-c R&D program:

- ✓ Corroborated the choice of operating parameters
- ✓ Exposed several areas of modest work
- ✓ Provided insight into operation of heavily wiggler dominated rings - e.g., LC damping rings
- ✓ Beam tests with full size prototype wiggler in CESR next month.